REVIEW

Modic changes: a systematic review of the literature

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Abstract Modic changes (MC) are a common pheno-
menon on magnetic resonance imaging (MRI) in spinal
degenerative diseases and strongly linked with low back
pain (LBP). Histology, radiology, potential mechanisms,
natural history and clinical studies of MC has formed the
foundation on which our understanding of spinal degene-
rative diseases is built. The objective of this study was to
provide a review of recent important advances in the study
of MC and their clinical significance. This review article
summarizes these studies, by delineating the possible
mechanisms, and raising doubts and new questions. The
related aspects such as discography and differential diag-
nosis with spinal infection and tumor on MRI are also
discussed. Although most of researchers believe that MC
are common findings in patients with spinal degenerative
diseases and have an association with discogenic LBP,
different results between studies may be produced from the
differences in study design, inclusion criteria, and sample
size. How the present knowledge of MC affects the man-
agement of spinal degenerative diseases remains unclear.
Further studies of MC will explore therapeutic possibilities
for future treatments of spinal degenerative diseases.

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Introduction

Signal intensity changes of vertebral endplates and sub-
chondral bone are often observed in magnetic resonance
imaging (MRI) in the patients with spinal degenerative
diseases. In 1988, Modic et al. [46, 47] summarized these
changes and classified them into three types, and then
modic changes (MC), as a medical term, were used in the
studies on spinal degenerative diseases. With further
research, MC was found to be one of parameters of the
morphological changes in spinal degenerative diseases on
MRI. Although the etiology of MC remains poorly
understood, some progress has been achieved in basic
research during the past two decades, including studies of
the prevalence and some clinical significance.

Materials and methods

Peer-reviewed, full-text articles were identified using a
Pubmed (http://www.ncbi.nlm.nih.gov/sites/entrez/) search
strategy with the keywords of Modic change(s), vertebral
endplate(s), low back pain, signal abnormality, magnetic
resonance imaging and discography. The search was
limited to studies on humans, published in English and in
the period from January 1987 up to February 2008.

To be included in the study, it was strictly necessary for
every article to provide information about the epidemiol-
ogy, natural history, clinical significance of MC. More than
300 articles were identified in the search, and 207 abstracts

and 68 full-text papers were read. Some of these articles recorded other information like differential diagnosis, mechanism, prevalence and distribution, relationship to discography. A total of 165 articles without adequate information regarding these issues were eliminated. Important studies were summarized in Tables 1 and 2 for further analysis.

Definition and classification

MC are bone marrow and endplate lesions visible on MRI. Bone marrow signal changes in the vertebral bodies were first reported by de Roos et al. [19]. Modic et al. [47] were credited with the classification of these signal intensity changes. Among 474 lumbar MRI performed in patients with LBP or sciatica, they observed MC type I [hypointense signal in T1-weighted imaging (T1WI) and hyperintense signal in T2-weighted imaging (T2WI), Fig. 1] corresponding to vertebral body edema and hypervascularity in 20 patients (4%) and MC type II (hyperintense signal in T1WI and hyperintense signal in T2WI, Fig. 2) reflecting fatty replacements of the red bone marrow in 77 patients (16%) in 1988. Afterwards, MC type III (hypointense signal in T1WI and hypointense signal in T2WI, Fig. 3) consisting of subchondral bone sclerosis were described by Modic et al. [46] at the same year and this type was much rarer.

In order to correspond to the Modic classification system, MC was divided into four grades by Miller [42] in 1990, namely grade 0: normal, no degeneration; grade one: equivalent to MC type I; grade two: equivalent to MC type II; grade three: equivalent to MC type III. Then, Weishaupt et al. [65], according to the vertebral height involved by endplate abnormalities on the mid-sagittal image, divided MC into four degrees: normal, no anomaly in T1, T2WI; mild, the scope of signal intensity changes equal to or less than 25% of vertebral height; moderate, the scope of signal intensity changes between 25 and 50% of vertebral height; and severe, the scope of signal intensity changes equal to or more than 50% of vertebral height.

Differential diagnosis from spinal infection and tumor on MRI

Although spinal infection and tumor may manifest like MC on MRI [9], the correct diagnosis is achieved usually by distinguishing their unique characteristics. With surrounding paravertebral soft-tissue edema or epidural mass effect, spondylodiscitis present as lesions with typically hyperintense signal on T2WI, compared to normal or hypointense signal on T2WI in degenerated disc, and with confluent hypointense signal on T1WI from the vertebral bodies and intervertebral disc space [9, 45]. In addition, the erosion of vertebral body and endplates are always observed in intervertebral disk space infection, whereas MC may be focal or diffuse along the endplates but tend to be linear and always parallel to the endplates [36]. In addition, the possibility of Schmorl's node must always be kept in mind. Schmorl's nodes are characterized by a localized defect (hypointense on T1WI and hyperintense on T2WI) in endplates with a well-defined herniation pit and a surrounding wall of hypointense signal (on T1WI and T2WI) in the vertebral body [66]. Although bone marrow edema and sclerosis on MRI may also be identified in patients with spondyloarthropathy [24], systematic symptoms and plain radiographs may help differentiate them from MC.

In fact, metastasis is the most common type of neoplastic lesion found in the spinal column. Rare instances of metastatic involvement of the disc have been noted [54]. Therefore, metastatic disease is readily distinguished from MC by the absence of disc space involvement.

Reliability of the classification system

In a special study on the reliability of the Modic classification [27], the authors found that the individual intraobserver agreement was substantial or excellent with kappa values ranging from 0.71 to 1.00 and the overall interobserver agreement was excellent with a kappa value of 0.85. Subsequently, Peterson et al. [50] reported the results of their study on the reliability of identifying and categorizing MC in clinical practice, showing that good intra- and interobserver agreement, especially at the L4–L5 level. In addition, other studies [16, 28, 36] with the kappa value at the range of 0.64–0.87 further supported intra- and interobserver reliability of the Modic classification system. Recently, Jensen et al. [26] confirmed that the "Nordic Modic Classification", as a detailed evaluation protocol of vertebral endplate signal changes, was reproducible and helpful to future studies.

These results suggest that the Modic classification system is reliable, simple and easy to apply for observers with various clinical experiences. With confirmation of the reliability of Modic classification, the results of previous studies using the Modic classification system are more credible and the comparability among these studies regarding MC further is strengthened. Therefore, it was suggested the use of this system in future studies for evaluating the relationship between patient symptoms and treatment outcomes.

Table 1 The prevalence and conversion of MC

| Authors	Study population	Sex (F/M)	Age	P	N	Prevalence (%)				Follow-up	Conversion (%)				
						All type	Type I	Type II	Type III		0 → I	0 → II	I → II	II → I	I → 0
Albert et al. [5]	Patients with sciatica		18–65	L	181	25[a]	10[c]	14	1	14 months	24[c]				
Chung et al. [16]	Asymptomatic subjects	31/28	20–75	L	59	8[b]	2	6							
Girard et al. [21]	Adult patients	28/12	23–80	T	40	2.3[b]	2.3			4–149 weeks	0.8	0.8			
Karchevsky et al. [28]	Consecutive patients	62/38	15–88	L	100	58[a]	24	33							
Kleinstuck et al. [33]	With chronic LBP	26/27	<65	L	53	62[a]									
Kjaer et al. [32]	General population	234/205	12–14	L	439	0.5[a]	0.5								
Kjaer et al. [31]	The general population aged 40	213/199	40	L	412	22[a]	15	7							
Kuisma et al. [36]	Unoperated sciatica patients	21/39	23–76	L	60	23[b]	2[c]	21		3 years	3[c]		0.7	2.6[c]	
Kuisma et al. [37]	Patients with LBP	0/228	36–56	L	228	16[b]	5	11				1			
Mitra et al. [43]	Patients with LBP or sciatica		18–70	L	670	18[a]	18			1–6 years			52		
Modic et al. [47]	Patients with LBP and/or sciatica			L	474	20[a]	4	16		1–3 years			83		
Peterson et al. [51]	Patients with neck pain	71/47	14–94	C	118	16[a]	11	2.5	4.2						
Toyone et al. [60]	Patients with LBP			L	500	19[a]									
Vital et al. [62]	Operated and with MC I	10/7	35–62	L	17	100[a]	100			6 months			76		24
Weishaupt et al. [65]	LBP patients	23/27	28–50	L	50	22[b]	14	8							
Weishaupt et al. [64]	Asymptomatic subjects	30/30	20–50	L	60	11[a]	2	7	2						

[a] The percentage of MC in study population

[b] The percentage of MC at per disc

[c] Including mixed type I and II

L lumbar, T thoracic, C cervical, P position, N number, MC Modic changes, LBP low back pain

Table 2 The relationship between MC and LBP

Author and location	Study population	Number	Association between MC and LBP	Other findings
Albert et al. [5] 2007 Denmark	Patients with sciatica	181	MC type I is more strongly associated with lumbar pain than MC type II	Disc herniation is a strong risk factor for developing MC (especially type I)
Carragee et al. [14] 2005 USA	Subjects with LBP or (non-lumbar) pain syndrome	100	MC are weakly associated with an adverse outcome	Psychosocial variables strongly predicted long- and short-term LBP problems
Jarvik et al. [25] 2005 USA	Veterans Affairs out-patients without LBP	148	No association between new LBP and MC type I	Depression is an important predictor of new LBP
Kjaer et al. [31] 2006 Denmark	40-year-old Danes	412	MC are strongly associated with LBP	People with LBP and MC may deserve to be diagnosed as having specific LBP
Kjaer et al. [32] 2005 Denmark	13-year old children	439	MC are strongly associated with LBP	
Kuisma et al. [37] 2007 Finland	Middle-aged male workers (159 train engineers and 69 sedentary controls)	228	MC show significant association with pain symptoms and increased frequency of LBP	MC at L5-S1 and MC type I are more likely to be associated with LBP than other types of MC or MC located at other lumbar levels
Schenk et al. [57] 2006 Switzerland	Female subjects with persistent LBP	109	MC are found to be significant risk factors for LBP	
Toyone et al. [60] 1994 Japan	Chronic LBP patients	500	MC type I are correlated with LBP	

MC Modic changes, *LBP* low back pain
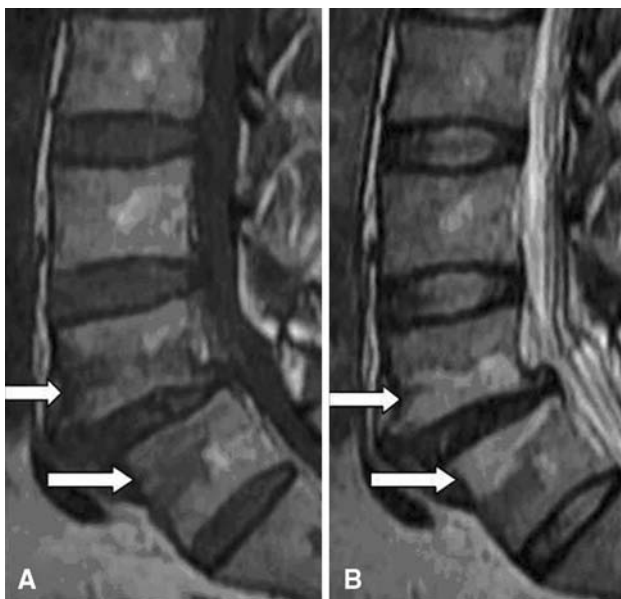
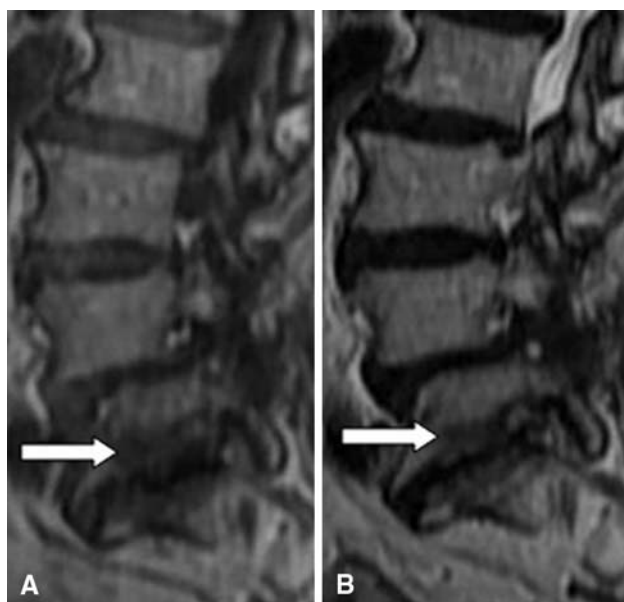**Fig. 1** MC type I (*arrows*): hypointense on T1WI (**a**) and hyperintense on T2WI (**b**)
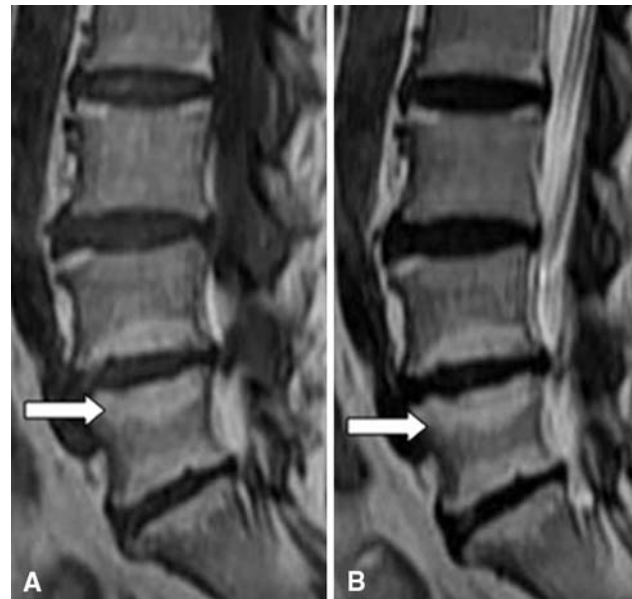
Fig. 2 MC type II (*arrows*): hyperintense on T1WI (**a**) and isointense or hyperintense on T2WI (**b**)

Prevalence and distribution

MC may be detected in the lumbar, cervical and thoracic spine of human being (Table 1) and in the spine of some animals [8]. The prevalence of MC varies from 18 to 62% in the patients with LBP, with different ratio for each type [5, 28, 33, 43, 47, 60]. According to the results of previous studies, type I and type II are the most common patterns in

Fig. 3 MC type III (*arrows*): hypointense on T1WI (**a**) and hypointense on T2WI (**b**)

the lumbar spine. However, it is disputed whether type II is more frequent than type I, whereas two studies have shown that type I may be more common [31, 65]. Meanwhile, Kjaer et al. [32] identified the prevalence of MC was only 0.5% in a study of 439 thirteen-year-old children. The inconsistent results between studies might be produced from the differences in study design, inclusion criteria, and sample size. Furthermore, MC are associated with increasing age, weight and male gender [28, 39].

Two studies showed that the prevalence of MC in asymptomatic persons was lower than in the patients with LBP. Chung et al. [16] investigated the frequency and distribution of MC in 59 asymptomatic subjects and found 11 MC type I and 38 MC type II in 590 lumbar vertebral endplates. In other study of 60 asymptomatic subjects by Weishaupt et al. [64], one reader identified that the prevalence of MC on MRI only was 11% in the study population (type I, 2%; type II, 7% and type III, 2%).

Three distribution characteristics of MC in lumbar spine should be noted. First, Modic et al. [47] observed that the distribution of MC at L4–L5 or L5–S1 were most common. These observations were confirmed by Kuisma et al. [37] Moreover, the depth and extent of MC were greatest at L4–L5 and L5–S1 [36]. Second, for the location of the signal changes, the distribution of type I and II was more in anterior 1/3 of vertebra than in posterior 2/3 of vertebra and the distribution of type II was predominant in the superior endplate versus in the inferior endplate [16]. MC are also characterized with being parallel on both sides of the disc and with vertical depth varied between 3 and 30 mm [36]. Third, the location according to Chung et al. [16] for

asymptomatic MC is at a higher level (superior endplates of L3 and L4) and anteriorly, whereas the symptomatic ones which apparently are at a lower level (surrounding the L4–5, L5–S1 discs) [36, 37, 47].

In contrast with plenty studies of MC in the lumbar spine, Peterson et al. [51] reported the prevalence and distribution of MC in the cervical spine in 118 patients with neck pain. In this study, MC was observed in 19 patients (16%) and type I and type III were far more common in the cervical spine with the C5–6 level being the most commonly involved. Girard et al. [21] found that MC was an uncommon manifestation of thoracic disc disease. The incidence of MC in thoracic vertebrae and endplates was 2.3% (11/480) and the new incidence was 1.6% (8/480) in 4–149 week follow-up, with the findings predominating in the lower intervertebral levels from T6 to T10.

Potential mechanisms

MC in subchondral bone and vertebra are not specific to degenerative disease [62] and can be detected on MRI in different conditions such as infectious, degenerative and immunological diseases. However, the pathogenetic mechanisms causing MC are not very clear. According to the current literature, there are two possibilities: biomechanical and biochemical causes (Fig. 4).

Biomechanics

Endplates play a very important role in the biomechanical functions of the spine. During human disc degeneration, the endplates undergo calcification with aging and replacement by bone, and exhibit altered structure, microfailure [22]. Such changes may lead to an uneven distribution of loads across the entire disc and thus may contribute to endplate fissures [47]. The endplates and vertebral body are 'weak link' of the spine, because microfractures and healing trabeculae are frequently observed in most cadaveric vertebral bodies [1]. In addition, the evidence provided by Adams et al. [1–3] showed that the loss of the nucleus pulposus, for the reason of bulging into the adjacent vertebra, herniation or desiccation and dehydration for severe degeneration, could increase the shear forces on the endplates and the trabeculae and result in the occurrence of the microfractures.

The microfractures and fissures in the endplates through the biomechanical mechanism may be a major source of MC. Modic et al. [47] demonstrated that MC type I was disruption and fissures of the endplates. If the microfractures take place recently, they will show the hypointense signal on T1WI and hyperintense signal on T2WI,

Fig. 4 Mechanisms and conversion of MC and effects of clinical intervention (adapted from Vital et al. [62])
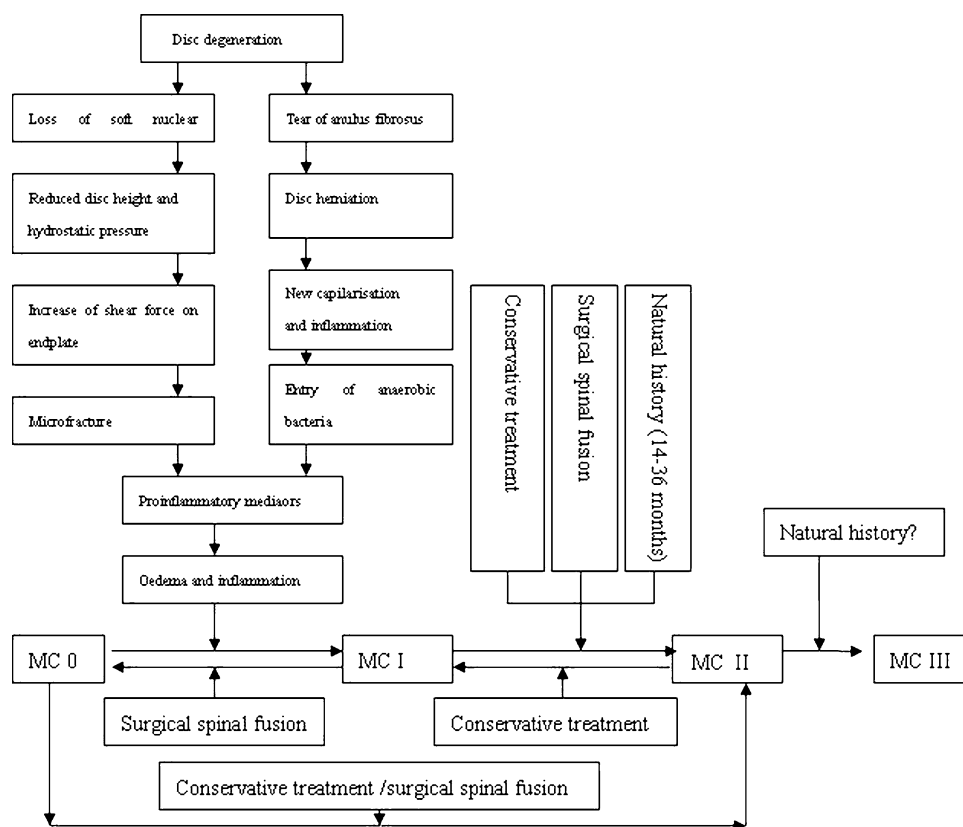
equivalent to MC type I [23]. Hence, this phenomenon might intimately reflect edema and vascularisation following cumulative trauma and an inflammatory response after microfracture in the endplates. The study by Schmid et al. [58] showed that hyaline cartilage in the extruded disc material from the patients with MC was more than those in patients without MC. The notion that MC may be the expression of altered mechanical stress was further supported by the observation that the conversion of MC type I to type II for the fusion and instrumented stabilization [62].

Although the exact causes of MC are not clear, their occurrence may be closely related to some mechanical stress [44]. The abnormal load and stress will affect vertebral endplates and the microenvironment of adjacent vertebral bone marrow, resulting in histological changes, which exhibit signal intensity change on MRI, namely MC [47].

Biochemical mechanism

Compared with the study of biomechanical mechanism, more studies have been carried out for the biochemical mechanism of MC. Crock et al. [17, 18] suggested that upregulation of inflammatory mediators in the nucleus pulpous could result in a local inflammation associated

with LBP. Therefore, MC possibly resulted from the inflammatory reaction by the toxic substances from degenerative disc [10]. Notably, the theory introduced by Albert et al. [4] claims that a disc herniation is the entry point of the bacteria and that MC likely are the result of entry of anaerobic bacteria resulting in oedema and inflammation surrounding the extruded nuclear material. However, this hypothesis has not been proved up to now.

Numerous studies have reported chemical anomalies involved in the disc herniation. The higher levels of pro-inflammatory mediator such as interleukin-6 (IL-6), interleukin-8 (IL-8), and prostaglandin E_2 (PGE$_2$) were observed by Burke et al. [11] in the discs of patients with LBP than in those with sciatica. Using the immunohisto-chemical method, Ohtori et al. [49] found that protein gene product 9.5 (PGP)-immunoreactive nerve fibers and tumor necrosis factor (TNF)-immunoreactive cells in the endplates from patients with MC was significantly more than in normal endplates on MRI. Moreover, the number of TNF-immunoreactive cells in endplates with MC type I was higher than in endplates with MC type II. The authors suggested that inflammation mediators and nerve ingrowth into vertebral endplates might be a cause of discogenic LBP and that MC type I was more likely resulted from inflammation mediators, whereas MC type II/III appeared to represent a more stable state. Additionally, it was

recently confirmed by Rannou et al. [53] that the level of high-sensitivity C-reactive protein (hsCRP) in patients with chronic LBP and MC type I was higher than in the patients with MC 0 and MC type II. These studies indicated that the upregulation of proinflammatory mediators within the degenerative disc may be the major origin of discogenic LBP. This is further supported by the study of Masaryk et al. [41], who produced MC in adjacent endplates by injecting chymopapain into the discs of patients with disc herniation. The authors believed that the endplate changes were inflammatory. The biochemical mechanism of MC is also supported by the fact that patients with chronic LBP and predominantly MC type I had better short-term efficacy following intradiscal steroid injection than those with predominantly MC type II [20].

Natural history and conversion between patterns

In order to clarify the differences among MC types, the conversion and natural history of MC have been assessed with a long- or short-term follow-up (Table 1). Modic et al. [46, 47] firstly found that MC type I in five of six patients converted to a type II pattern in 14 months to 3 years without any intervention and MC type II in ten patients remained stable over a 2 to 3-year period. Subsequently, in a follow-up study for 12–72 months of 48 disc levels with type I, Mitra et al. [43] identified 18 (37.5%) converting fully to type II, 7 (14.6%) partially converting to type II, 19 (39.6%) becoming worse (more extensive type I) and 4 (8.3%) showing no change. In another 3-year study, 10 of 70 discs (14%) with MC at baseline displayed another type at final follow-up [36]. According to the current literature, the interconversion among type 0, I and II possibly occur. The conversion of type I to II is most common and the time span of different conversion is at least 1 year.

Most of conversions are often localized at L5–S1 and colocalized with a symptomatic disc herniation [36]. However, the new MC are more remarkable phenomenon. Kuisma et al. [36] reported the incidence of new MC during the 3-year follow-up was 6% (13 of 230). Most of new MC were found also at L4–L5 or L5–S1, and colocalized with a symptomatic disc herniation. These findings were confirmed by Albert et al. [5], who found that the incidence of new MC type I was closely related to a previous disc herniation and higher in patients who had undergone surgery for lumbar disc herniation.

MC type I appear to be more fluid and variable and will become seriously or convert into type II in most cases, whereas MC type II appear to be a more stable state. However, MC type II is not unchangeable and may convert into MC type I in unstable conditions. Given the current evidence, the incidence of type I converting to II, type I

converting to 0 (normal), and type II converting to I degraded in order. Consequently, MC type I represent the major transition point with normality and it is the intermediate process from the early degeneration induced instability to restabilization at later stage.

Nevertheless, Marshman et al. [40] recently detected the unstable and symptomatic MC type II in two cases. Although MC type II transformed reversely into MC type I in two female patients, the severity of chronic LBP did not change. Therefore, the authors thought that MC type II was not stable and quiescent as originally believed. Furthermore, mixed MC (I/II and II/III) have also been identified, suggesting that all MC perhaps are interchangeable from one type to another and that they all present different stages of the same pathologic process [10, 36]. It is possible that direct conversion among MC types should be justified in the future study.

Relationship to LBP

It is frequently stated that only a small proportion (approximately 20%) of patients with LBP can certainly be diagnosed based on a pathoanatomical entity [63]. To clarify the relations between MC and LBP, a series of prospective studies have been conducted (Table 2). The study of Albert and Manniche [5] showed that the prevalence of MC type I increased from 9% at baseline to 29% during the follow-up in patients with LBP, indicating a strong association between MC (especially type I) and nonspecific LBP. Similar results have been described by Kjaer et al. [30, 31] in the study of 412 40-year-old Danes. Afterwards, Kuisma et al. [37] showed that MC at L5–S1 and MC type I are more possible to be related with LBP than other levels and types of MC. Isolating the subgroup of the patients with MC and LBP may deserve with diagnostic and therapeutic interest. Nevertheless, a 5-year follow-up study by Carragee et al. [14] showed that moderate or severe MC were weakly associated with poor outcome in the patients with persistent LBP. Meanwhile, Jarvi et al. [25] showed that MC type I was not a risk factor of new LBP in a study of 148 outpatients without LBP, indicating that the appearance of LBP and the occurrence of MC perhaps did not synchronize.

Most of the results aforementioned confirmed that MC are strongly linked with discogenic LBP, but there exist controversies regarding the relationship between MC and the outcomes following clinical intervention or new LBP. The controversies may come from either the differences of inclusion criteria, study methods and sample size, or the differences of the compliance, social and psychological factors in selected patients and the experience of the researchers.

How can MC cause the pain? Pain may be generated from all types of tissue where free nerve endings are present, these have been demonstrated as they are present in most types of tissue in the spinal column [7, 15]. Pathological changes of these structures will stimulate inevitably the corresponding pain receptors, thus resulting in pain. Other than mechanical problems of the spine, a large number of inflammatory and signaling substances, including different cytokines such as TNF, IL-6, IL-8 and PGE$_2$, have been suggested to play a role in LBP [11, 49]. In a randomized trial, Korhonen et al. [35] evaluated the long-term efficacy of infliximab (a monoclonal antibody against TNF-α) in patients with acute/subacute sciatica secondary to disc herniation. The patients in the infliximab group appeared to be treated with better efficacy in cases of a L4–L5 (or L3–L4) disc herniation with the concurrence of MC, although similar efficacy was noted between infliximab and placebo group. Therefore, there may be an association between TNF-α and LBP induced by MC. Accordingly, the obvious variation of inflammation mediators in the endplates with MC would be one of the causes of LBP. Then, the reason that MC type I is more associated with LBP perhaps is that MC type I represents the earlier stage of inflammation and produces more proinflammatory chemical mediators.

Some authors investigated the MC among different occupational groups. An MRI study [57] was performed in 109 female subjects selected from nursing and administrative professions with LBP. Only nerve root compromise and endplate changes in the lower lumbar spine were significant risk factors for LBP. However, there is the similar incidence of MC in nurses and administrative workers with LBP (30.4 and 29.4%, respectively). Kuisma et al. [37] studied 228 middle-aged male workers (159 train engineers and 69 sedentary). The prevalence of MC was similar in both occupational groups. The two results may provide the evidence that the type of occupation will not influence on the incidence of MC.

Furthermore, a MRI study [59] of 125 patients showed an incidence of 4.8% for retrolisthesis combined with MC at L5–S1 level and the coexistence of retrolisthesis and MC were more often in the smokers and those without insurance. The relationship between heavy smoking and MC also was showed by Leboeuf-Yde et al. [39]. Additionally, MC in the pedicles adjacent to spondylolytic defects on MRI were noted by Ulmer et al. [61] in 24 (40%) of the 60 patients with lumbar spondylolysis. These findings may provide assistance in diagnosing correctly spondylolysis on MRI.

Relationship to discography

At present, it is disputed that discography is an effective means to diagnose discogenic LBP. In a discography study [10], the presence of MC showed a highly significant association with pain reproduction at discography. Toyone et al. [60] reported that when the signal intensity changes in the endplates and decreased signal intensity in degenerative lumbar discs were combined, the specificity of using MRI to diagnose disc pain disease would increase from 79 to 97%. The signal intensity changes in endplates indicate a high degree of specificity, but the lack of sensitivity in discogenic LBP. Buttermann et al. [12] also confirmed that MC have high pain sensitivity on discography (severe concordant pain at low intradiscal pressures).

MC are of important value in the diagnosis of discogenic LBP, but MRI does not completely replace the discography due to the lack of the sensitivity. MRI was performed immediately before and within 2 h after uncomplicated lumbar discography in a study of 20 consecutive patients [55], and 7 of them were reassessed average 72 days after discography. The results showed that the uncomplicated lumbar discography would not lead to the occurrence of new MC. However, in other studies [34, 56], pain reproduction at discography were not evidently linked with the presence or absence of the lumbar MC. Therefore, further studies would be required to determine the association between discography and MC.

Clinical intervention and prognosis

As different types of MC may have different clinical significances, the influence of clinical intervention on MC has been evaluated regarding surgical and conservative treatment (Fig. 4).

Arthrodesis is a common surgical method for the patients with spinal instability. In the study of Lang et al. [38], it was suggested that the occurrence of MC type I are the signs of the pseudarthrosis formation by evaluating segmental spinal instability in 33 patients after spinal fusion. This result was consistent with the observation of Buttermann et al. [13] that nonfusion was associated predominantly with the persistence of MC type I. Toyone et al. [60] found that patients with MC type I tended to show hypermobility, when compared with those with MC type II, and require fusion surgery. Additionally, MC also has an impact on surgical results. Kim et al. [29] reported that the presence of MC was a risk factor for recurrence after successful percutaneous endoscopic lumbar discectomy. Similar result by Barth et al. [6] was shown that MC was a factor of the etiology of unfavorable clinical outcome after surgery for disc herniations.

It has been found that most MC type I naturally tend to convert to type II in 18–24 months [47, 62]. Nevertheless, the clinical intervention may effect on the course of MC.

Vital et al. [62] examined 17 patients with MC type I using MRI 6 month after posterior instrumented posterolateral fusion and found the conversion from type I to type 0 in 4 patients and from type I to type II in the remaining 13 patients. It appears that posterior fusion accelerates the course of MC type I, probably by correcting mechanical instability. Putzier et al. [52] compared sole nucleotomy with nucleotomy and additional dynamic stabilization in the treatment of symptomatic disc prolapse in 119 patients with MC type I. At 3 months follow-up, accelerated segmental degeneration existed in the solely nucleotomized group but no progression of disc degeneration was noted in the dynamically stabilized group. It is thus evident that the changes of mechanical conditions in spinal segments would slow the proceeding of MC.

Up to now, there are not unanimous conclusions on minimally invasive surgery for treating degenerative disc diseases with MC. The evidence [12] showed that spinal steroid injections were more effective for treating lumbar degenerative disc diseases with MC. However, there were no changes of MC and disc height after the intradiscal electrothermal therapy procedure in the patients with symptomatic intervertebral disc [48].

According to the information aforementioned, there are intimate relations between MC and the outcomes following clinical intervention. Good efficacy of clinical intervention on MC type I have been shown, even if those studies have the limitations of small sample size and short-term follow-up. The studies regarding MC type II and III are still scant. Although stabilization or fusion procedure has been suggested for the patients with symptomatic MC type I, this recommendation seems somewhat premature according to our current understanding of MC. Further studies are required to delineate the natural history of MC and to determine the relationship to biomechanical factors and symptoms. In a logical sense, an animal model would be necessary to prove these hypotheses. Unfortunately, this is not the case [44].

Summary and perspective

MC are a common phenomenon on MRI of spinal degenerative diseases. Two hypotheses, the biomechanical and biochemical causes, are possibly potential mechanisms underlining MC. To date, however, the evidences supporting the two hypotheses are not sufficient and how they play a synergistic role in the process of MC in the human body is not clear. Furthermore, the conclusion that patients with MC are a specific subgroup within LBP patients perhaps be premature, although MC have been strongly associated with LBP according to current evidence. The natural history and conversion of MC can be affected by some measures of clinical intervention, which do not aim directly and specially at treating MC but other diseases or symptoms.

Areas of future research should mainly include the mechanisms, natural history and relationship to symptoms. The substantial mechanisms of MC are very important for the patients with LBP because they possibly lead to a correct diagnosis. Identification of a precise mechanism for the factors involved in the progression of MC may be helpful for clinical treatment. Hence, two problems are urgently needed to be solved that the clarification of the determinants of resulting in LBP in patients with MC, and the interpretation that how these potential mechanisms synergize with together. Mechanisms of spontaneous conversion are of great importance for efforts to repair or step down the development of MC through clinical intervention. Therefore, further studies with longer follow-up periods, more frequent MRI and larger sample size will be required to reveal what factors contribute to the conversion of MC [40]. Clinically, how the knowledge of MC we understand currently can affect the management remains unclear. More prospective randomized clinical trial shall be carried out to reveal the relationship between MC and clinical symptoms, although clinical intervention, such as conservative and surgical treatment, is efficient to the patients with LBP and MC. The outcome of such research will explore the novel possibilities for future treatments of spinal degenerative diseases.

Under ideal circumstances, we should have a rodent model to solve these problems. The establishment of animal models is possible because signal intensity changes on MRI have been identified in thoracolumbar endplates in dogs [8]. However, there are certainly many difficulties in establishing the models for reasons that the long duration of MC and the necessity of frequent MRI.

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